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A Laboratory Study of Convectively-Driven Mean Flow in a Model of the Red Sea

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LONG-TERM GOALS

The goal of the project is to gain an understanding of the density and velocity fields created by a surface forcing, e.g., buoyancy flux and wind stress, in partially enclosed seas with hydraulically constricted exits. Applications to the Red and Mediterranean Seas are foremost in our thinking but the flows in fjords and other embayments of this type are also of interest.

OBJECTIVES

We wish to determine the scaling laws that relate the density and velocity distributions to the independent variables in the problem. The latter would include the magnitude of the buoyancy flux and wind stress and the geometry of the sea and the exit strait. Hopefully these should then lead to a more complete understanding of the prototype and to suggestions for suitable field experiments.

APPROACH

In order to understand the problem outlined above we have built a small-scale laboratory model (2.5m long) that simulates most of the conditions encountered in the natural system. This model has been run over a wide range of operating conditions of buoyancy flux and model geometry so as to gain a better understanding of both the scaling laws and the physical mechanisms that are important in this system. A larger facility has also been constructed in order to test the relative importance of viscous forces on the results found in the original test rig.

WORK COMPLETED

The effects of buoyancy flux and different strait geometries, consisting of a simple sill with or without moderate lateral contractions, have been completed (Grimm and Maxworthy, 1998). We have also run a number of tests with contractions of a larger range of widths. In the same series of experiments the location of the contraction with respect to the sill has been varied as well as was the relative length of the buoyancy sources. A larger test tank has been constructed but substantive testing has been delayed by the difficulty of obtaining good flow quality in the test section.

RESULTS

While the interface drop over the sill has been found to agree with the results of classical one-layer hydraulics the drop from the downstream edge of the source region to the region just before the sill has been found to depend on the position of the sources as well as the contraction ratio of the strait at the sill. This surprising result has been partially explained using ideas from the classical theory of exchange flows and will be the focus of continuing work. Experiments to explore the effect of the location of the contraction relative to that of the sill have shown a small effect when the strait is on the side of the sill facing the enclosed sea. The values of g' are typically 90% of the values when sill and contraction coincide for modest contraction ratios. The effects of varying this ratio over a wider range are underway.

Results from the larger tank have been slow in coming due to a major problem. Scaling the original tank up by a factor of four in all dimensions has resulted in an inability to generate a uniform buoyancy flux over the buoyancy sources. Many attempts to improve the quality of the flow have not been successful. However, recently a new porous material for the base of the sources has been found and ordered and hopefully this will solve the problem.

IMPACT/APPLICATIONS

The laboratory model appears to support the claim that the surface-to-depth density difference has a linear dependance with distance from the closed end of the sea. This is consistent with existing measurements during some portion of the seasonal cycle. Also, the model shows the importance of intense mixing at the closed end of the sea and the details of the hydraulic flow at the narrow/shallow strait. These observations could be tested during a field program that uses the experimental results to concentrate on a few, well-chosen locations for detailed measurement rather than trying to survey the whole sea at low spatial resolution.

PUBLICATIONS

Grimm, T., 1997, "Dichteinduzierte Stroemungen in einem Langen Kanal," PhD Thesis, Georg-August-Universitaet zu Goettingen.

Grimm, T. and Maxworthy, T., 1998, "Buoyancy-driven Mean-flow in a Long Channel with a Hydraulically-constrained Exit Condition," J. Fluid Mechs. 398, 155-180.